The response to prism deviations in human infants

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Previous research has suggested that infants are unable to make a corrective eye movement in response to a small base-out prism placed in front of one eye before 14–16 weeks [1]. Three hypotheses have been proposed to explain this early inability, and each of these makes different predictions for the time of onset of a response to a larger prism. The first proposes that infants have a 'degraded sensory capacity' and so require a larger retinal disparity (difference in the position of the image on the retina of each eye) to stimulate disparity detectors [2]. This predicts that infants might respond at an earlier age than previously reported [1] when tested using a larger prism. The second hypothesis proposes that infants learn to respond to larger retinal disparities through practice with small disparities [3]. According to this theory, using a larger prism will not result in developmentally earlier responses, and may even delay the response. The third hypothesis proposes that the ability to respond to prismatic deviation depends on maturational factors indicated by the onset of stereopsis (the ability to detect depth in an image on the basis of retinal disparity cues only) [4,5], predicting that the size of the prism is irrelevant. To differentiate between these hypotheses, we tested 192 infants ranging from 2 to 52 weeks of age using a larger prism. Results showed that 63% of infants of 5–8 weeks of age produced a corrective eye movement in response to placement of a prism in front of the eye when in the dark. Both the percentage of infants who produced a response, and the speed of the response, increased with age. These results suggest that infants can make corrective eye movements in response to large prismatic deviations before 14–16 weeks of age. This, in combination with other recent results [6], discounts previous hypotheses.

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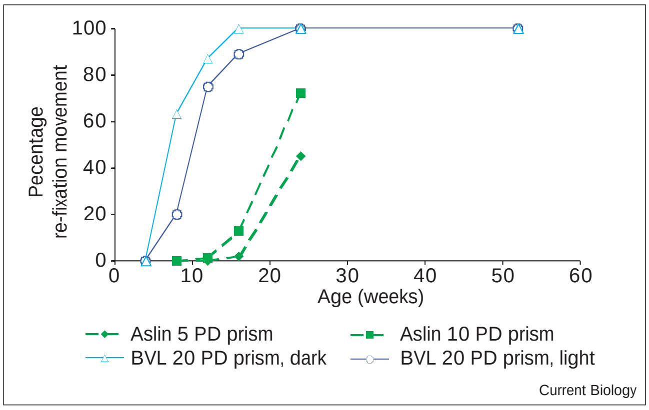
Results and discussion

Figure 1 shows a comparison between the results obtained by Aslin [1] using 5 and 10 PD (prism dioptres) base-out prisms, and the results of our study using a 20 PD base-out prism. At all comparable ages, the percentage of infants that overcame prismatic deviation in our study was larger than that reported by Aslin [1]. Additionally, in our study, infants aged up to 24 weeks were more likely to overcome the effects of the prism in the dark than in the light. By 16 weeks, 100% of the infants tested could overcome the effects of the 20 PD prism in the dark.

Figure 2 shows these results broken down by age and behaviour; responses to the prism in both the light and the dark are shown. Figure 2a shows the response in a well-lit room, and Figure 2b gives the results when the infants were tested in the dark. These results show that the response to, and/or recovery from, the prism is often slower in infants younger than 16 weeks than the responses of older infants (Figure 2) and adults [7]. Rapid responses are found at an earlier age in the dark than in the light.

These data make it possible to discount two of the theories outlined above. Infants cannot be learning to make corrections to larger disparities on the basis of experience with small disparities (Hypothesis 2 [3]). Furthermore, if the response to prismatic deviation required similar mechanisms to stereopsis (Hypothesis 3), then no corrective movements to prismatic deviation would be expected until

Figure 1



Comparison of the percentage of infants of each age group tested who made a corrective eye movement in response to prism placement in this study and in Aslin's study [1]. The comparison shows that more infants made a corrective eye movement as prism size was increased (compare Aslin 5 PD prism, Aslin 10 PD prism, and 20 PD prism, light, this study). Infants who were less than 24 weeks old in this study were more likely to make a corrective eye movement in the dark than in the light. The biggest difference was found at 5–8 weeks, when more than half of the infants (63%) responded positively in the dark compared with 20% of the infants in the light.

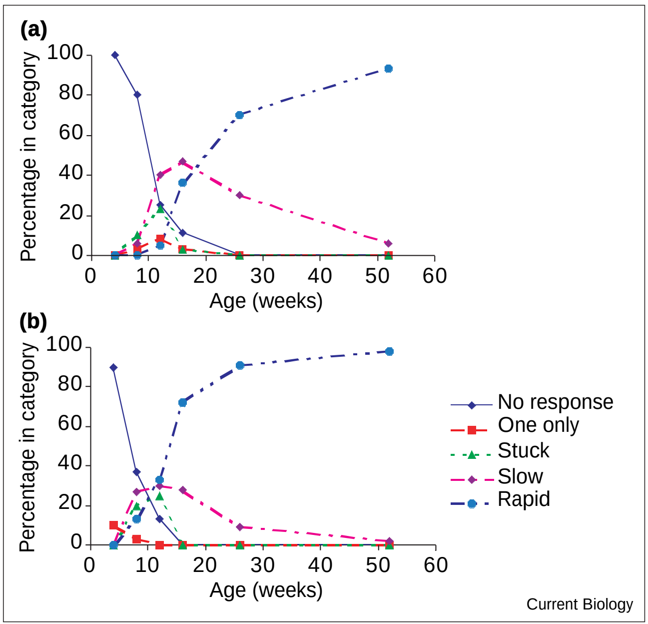


Figure 2

Types of corrective movement made by infants in each age group tested. Performance was tested **(a)** in the light and **(b)** in the dark. Infants were scored as follows. 'No response': no response to prism placement on any test (dark blue diamonds). 'One only': an adduction (a corrective movement) of the eye behind the prism and recovery on one occasion only of repeated trials (orange squares). 'Stuck': a slow adduction of the eye behind the prism, with no recovery for at least 5 sec after removal of the prism on each test (green triangles). 'Slow': a slow adduction of the eye behind the prism and/or slow recovery on each test (purple diamonds). These movements lasted more than 0.5 sec. 'Rapid': a rapid adduction of the eye behind the prism and a rapid recovery movement on each test (light blue circles). These movements were completed within 0.5 sec. The youngest infants tested (4 weeks of age) did not respond to the prism, but by 8–12 weeks, about half of the infants were responding, with more infants showing rapid responses in the dark than in the light.

after 14–16 weeks of age [5]. This leaves only one current explanation for the findings presented here: Aslin's suggestion that his findings could be due to degraded sensory capacity and hence that larger prismatic deviations might induce corrective eye movements in younger infants [2]. Other researchers [6], however, have shown that infants as young as 7 weeks of age are able to respond to smaller (4 PD base-out) prisms than tested by Aslin. There appears to be some dispute over the age at which infants can overcome the effects of small prisms. These differences might be the result of attentional differences between the infants tested in each study, or other methodological considerations, and further evidence is required to resolve this issue. This would include testing the same infants with prisms of different sizes.

An alternative hypothesis that explains the available data more completely and parsimoniously can be based on an elaboration of Held's two-stage theory for the development of binocularity. Held [5] suggests that early binocular responses could result from bifoveal fixation, that is, that each eye is controlled separately early in development. In support of this hypothesis, it has been shown that infants superimpose different images viewed by each eye before, but not after, the onset of stereopsis [8]. This demonstrates that infants younger than 14–16 weeks do not respond to diplopia (double images) in the same way

Figure 3

Photograph of the testing situation in the light showing the glow worm toy which was used as a target in this study. The inset shows the appearance of the glow worm in the dark.

Figure 4

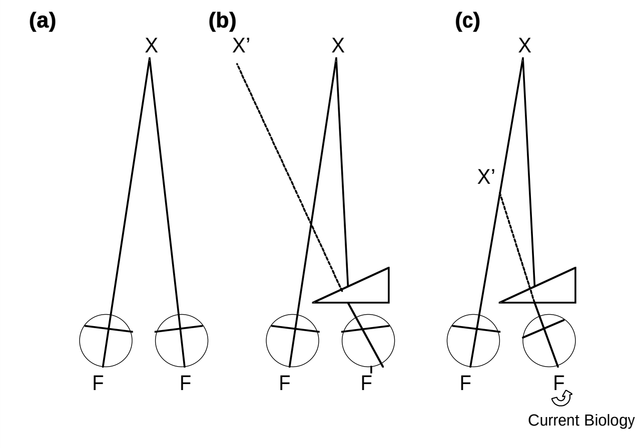


Diagram of the effect on eye position in an adult of placing a base-out prism in front of one eye. In (a) the eyes are fixating an object at point X. The point 'F' shows the position of the fovea. In (b) a prism is placed in front of one eye, displacing the image of point X temporally on the retina, away from the fovea. The image of point X in this eye therefore appears to be shifted to the left in visual space in this eye. A corrective eye movement (adduction) is required to return the image of object X to the fovea: This is seen in (c). The intersection of the lines of sight of the two eyes determines, for adults, where the object will be located. It can be seen from (c) that placing a prism in front of one eye results in the target being relocated in depth (X').

as adults, confirming the idea that early responses are not driven binocularly. Instead, when the image in one eye is moved away from the point on the retina consistently used by an infant to fixate objects, a refixation movement of that eye might be triggered to bring the object back onto that part of the retina. It is known that young infants consistently use one part of the retina for monocular fixation before the fovea is fully developed [9]. This would explain the difference between infants' behaviour in a well-lit room compared with a darkened room as there is only one prominent target in the dark, whereas multiple targets could compete for attention, and become superimposed, in the light.

We conclude, therefore, that infants are capable of a response to prismatic deviation before the age at which this response could be effectively driven by disparity mechanisms. This response appears to involve a primitive mechanism as it does not have the same temporal characteristics as the mature response. We suggest that it provides evidence for an early response that aligns infants' eyes using a process of bifoveal fixation.

Materials and methods

Subjects

Eighty-eight healthy infants aged from 2 weeks to 1 year and with no known strabismus or other ocular defects were tested when awake and alert. Each infant was tested between one and seven times, giving a total of 192 responses. The data from these infants have been pooled to show cross-sectional developmental changes in response; but, the small number of infants who were tested across the whole developmental range showed similar longitudinal time-courses to the cross-sectional data presented here.

Infants were tested in two conditions: a well-lit room where there were many competing targets to which the infant could attend; and a darkened room where the only target was a self-illuminating toy. The infant's attention was drawn to a brightly coloured toy (Glow Worm, Playskool, Hasbro Inc.) with a face which extended approximately 20 degrees of visual arc when held about 30 cm from the infant (Figure 3). In the darkened room, a torch could be illuminated inside the glow worm, which caused the face to light up. This provided a bright visual target for the infant as well as illuminating the infant's face for detection of the eye movement (Figure 3; insert).

When the infant was attending to the toy, a prism was placed in front of one eye. The eye under the prism was observed for evidence of a refixation movement to bring the image of the toy back onto the fovea in that eye. Figure 4 shows the adult response to placement of a prism.

If no refixation movement occurred, the toy was moved slowly towards and away from the infant to stimulate the refixation movement. This was discontinued either when a refixation movement had occurred or after 20 sec. The prism was then removed and, if the infant had responded to the prism, the recovery movement was observed. The prism was then placed in front of the other eye and the movement observed. This whole procedure was repeated at least twice. Two observers were used, one of whom is a senior orthoptist. Consistency across observations was achieved by initial training by the orthoptist.

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